The impact parameter of the particles at the scraper and ways to increase it.

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Abstract

The average impact parameter of the particles at the scraper face, which depends on the drift transverse speed and beam size, is defined and the ways for its increasing are considered. Influence of pulse orbit, slanting scraper and scattering target on the impact parameter is investigated.

1 INTRODUCTION

When we create scraper system the increasing of the impact parameter of the particles at the scraper face has very big significance for its work [1-3]. That reduces its heating and number of secondary particles, which escape from the system, simplifies the process of scraper's alignment and creating technology. Transverse drift speed and amplitude of betatron oscillations for scraping particles depend on system working regime and define impact parameter. As will be shown in the following sections, the impact parameter of the particles may be increased due to special methods.

2 THE IMPACT PARAMETER WITH THE CONSTANT TRANSVERSE DRIFT SPEED

When we form beam, particles come to the scraper with the help of bump-magnets or by other ways. Figure 1 shows their moving on the normalized phase plane. When amplitude of betatron oscillations A is bigger then distance from equilibrium orbit to the edge of the scraper R_s, particles may be lost on the scraper. If scraper absolutely absorbs particles with uniform distribution on the angle, the probability to lose the particle in one turn in normalized phase coordinates is:

$$P(A) = \frac{\varphi}{2\pi} = \frac{1}{\pi} arccos(R_s/A), \qquad (1)$$

where φ is the angle inside which particles reach the scraper. Probability to lose the particle with amplitude A is:

$$P_s(A) = \int_{R_s}^{A} \frac{dA \times arccos\frac{R_s}{A}}{\pi \times V(A)}, \quad where \quad V(A) = \frac{dA}{dn}.$$

The particle flux through the phase surface limited by amplitude is defined like $\Phi(A) = \Phi(R_s)e^{-P(A)}$, where $P(A)$ is probability to lose the particle if it will reach amplitude A.

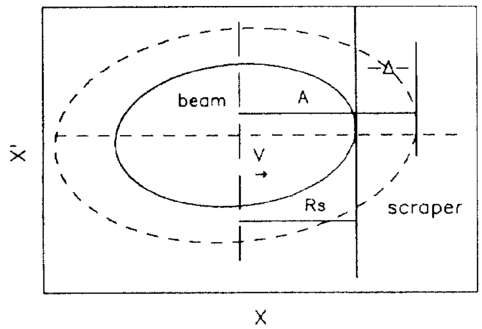

Figure 1: Phase plane.

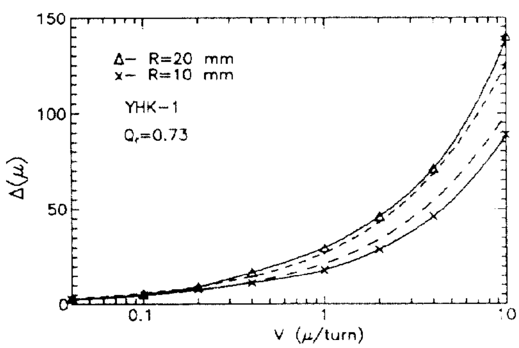

Figure 2: Dependence of the average impact parameter from the transverse velocity of the beam.

Density of particles depends on amplitude in a following way:

$$\rho(A) = \rho_0(R_s)e^{-P(A)}V_0(R_s)/V(A). \qquad (2)$$

If transverse velocity is small, i.e. the orbit distortion for one turn $R_s/V \gg 1(turn)$, the probability to lose the particle equals:

$$P_s(A) = \frac{2}{3\pi V}\sqrt{2x^3/R_s}, \quad where \quad x = A - R_s. \qquad (3)$$

The average impact parameter of the particle for amplitude may be defined like:

$$\Delta_A = \int_0^\infty x\rho(x)dx \Big/ \int_0^\infty \rho(x)dx. \qquad (4)$$

By using expression (2) in order to determine particle density: $\rho(x) = \rho_0 e^{-cx^{3/2}}$, where $c = \frac{2\sqrt{2}}{3\pi V\sqrt{R_s}}$, and putting the result in (4), we can find the average impact parameter for output coordinate: $\Delta_A \simeq 1.5\sqrt[3]{V^2 R_s}$. Taking into account the uniform distribution on the angle φ for particles (see

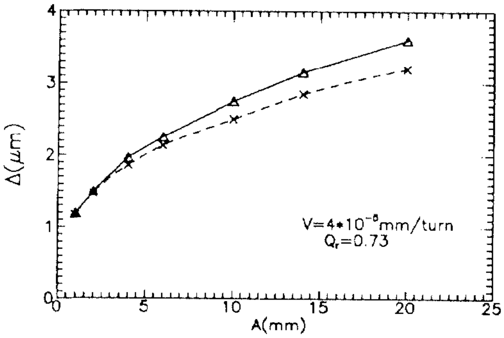

Figure 3: Dependence of the average impact parameter from the amplitude of betatron oscillations.

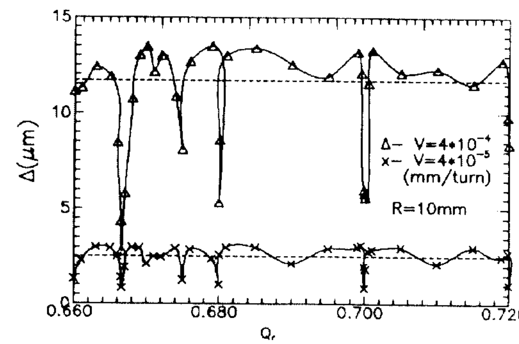

Figure 4: Dependence of the average impact parameter from the frequency of betatron oscillations.

Fig.2), one can obtain the average impact parameter for output coordinate: $\Delta_R = \int_{\varphi_{min}}^{\varphi_{max}}(A\cos\varphi - R)d\varphi/(\varphi_{max} - \varphi_{min})$. If particle amplitude changes slowly $\Delta \ll A$, as in case of scraping halo beam, the impact parameter is :

$$\Delta_R \simeq 2\Delta_A/3 = \sqrt[3]{V^2 R_s}. \tag{5}$$

That is the impact parameter increases with the transverse velocity and beam size (see Fig.2,3). That's why it is desirable to increase β-function at the place the scraper installed, since half beam size is defined $R = \sqrt{\beta\varepsilon}$, where ε is beam emittance. Analogical conclusion may be done in case of orbit displacement with $V(\Delta) = d\Delta/dn$. Transverse velocity of the beam V depends on working regime of scraper system and it may be increased. But for high intensity accelerators, such as UNK, at very big transverse velocity ($V \sim 10^{-2} \div 10^{-1}$mm/turn) may occur thermal destructions of not only the scraper, but even the target.

The computer experiment on drifting particles to the scraper was made at various velocities and amplitudes of betatron oscillations. The results, calculated by the program "Scraper", are presented on fig.2,3. Program "Scraper" simulates the particle movement in accelerator, which elements are presented by six-dimensional matrix. In order to speed up the calculation process the part of circle, where particles cannot be lost, replaced by one matrix. In program besides the betatron oscillations the synchrotron oscillations are taken into consideration. By passing particles through target the process of multiple coulomb scattering and nuclear interaction with atoms of matter are simulated.

The above-mentioned calculations of the impact parameters, depended on the transverse velocity and amplitude, were obtained from formula (5) (see dashed curves on fig.2,3) and they almost coincide with data made by computer simulations of process (see solid curves). This fact proves the obtained expression (5) in spite of some admissions during its creation.

The impact parameter also depends on the betatron oscillations frequency. Near the resonant lines $Q_r \times m = n$, where m and n are integer numbers, the impact parameter sharply decreases (see fig.4). This happens because the particles on the phase plane after m turns come practically to the same points and hence have smaller impact parameter then in case of uniform particles distribution on angle at the scraper.

The impact parameter in beam forming regime is very small - several μm (see table 1). It causes the increasing of particles density on the edge of scraper and therefore there is a danger of its destruction and considerable equipment irradiation due to high probability of proton output from the internal scraper surface.

Abortion of high intensity halo beam on the target's edge may also lead to its destruction and then to the collapse of all scraper system. Analogically, when we use crystal for beam extraction, only its edge is working. That causes the considerable radiation damage and thermal heating and leads to necessity of high quality processing of crystal surface.

3 INFLUENCE OF THE ORBIT INSTABILITY

The instability of the beam orbit essentially influences on the value of impact parameter. The cause of orbit pulsations may be as the pulsations of magnetic field as the synchrotron oscillations with nonzero dispersion. Let us suppose that the orbit displacement changes periodically with frequency ω and amplitude B. Then, as it seen from fig.5, the transverse velocity of particles at the scraper includes the constant guide velocity V_0 and derivative of pulsing orbit displacement coordinate $V = V_0 + B\omega \times \sin(\omega t + \varphi_0)$. If we know the average impact parameter as function of velocity $\Delta(V)$, then we can find average impact parameter as

$$\Delta \simeq \int_0^T \Delta(V)dI / \int_0^T \rho(A)dA.$$

Since the number of scraped particles with $V > 0$ is proportional to scraping velocity and time: $dI = V\rho(A)dt$, then for one pulsation period the number of scraped particles is: $\int_0^T \rho(A)dA = \rho(A)TV_0$. After that we can define the average impact parameter

$$\Delta \simeq \frac{\sqrt[3]{R_s}}{2\pi V_0} \times \int_{\varphi_1}^{\varphi_2} (V_0 + B\omega\sin\varphi)^{\frac{5}{3}} d\varphi. \tag{6}$$

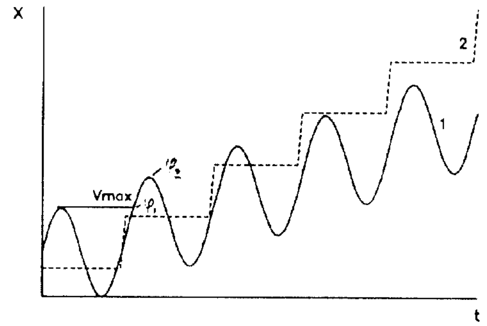

Figure 5: Changing of particle displacement near the scraper. 1- pulsations of equilibrium orbit, 2- special perturbation of orbit.

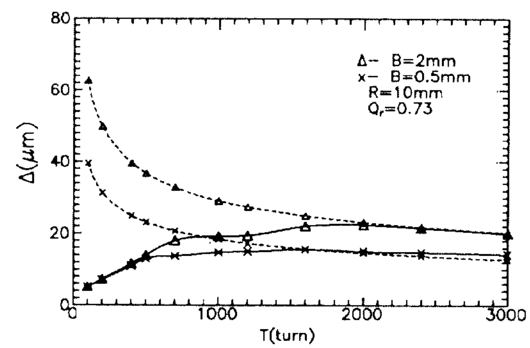

Figure 6: Dependence of the average impact parameter from the frequency of pulsations.

At slow and small pulsations $\omega B < V_0$ the integration limits are defined like $\varphi_2 = \varphi_1 + 2\pi$. In the other case they are defined from the equations $V(\varphi_2) = 0$ and $V(\varphi_1) = V(\varphi_2 - 2\pi)$ (see fig.5). If $\omega B \gg V_0$, as for scraper system in UNK, then for orbit pulsations due to synchrotron oscillations we can find from the equations (5) and (6) :

$$\Delta \simeq 1.7 \times \sqrt[3]{R_s V B \omega}. \qquad (7)$$

That is the impact parameter grows with increasing of amplitude and decreasing of pulsation period. Computer simulation of drifting the beam to the scraper was made with changing the orbit pulsation period (see fig.6). Created curves of the impact parameter are represented by solid line. They behave themselves as well as the curves calculated on formula (7) (dashed lines) at the pulsation period T more then $\sim$ 1000 periods of turn and decrease to value of the impact parameter with constant transverse velocity (eq.(5)) at the pulsation period compared with period of turn.

Figure 7 shows the dependence of the average impact parameter from the orbit pulsations . Created curves confirm the character increasing of the amplitude and the increasing of impact parameter along with the increasing of the pulsation amplitude.

Hence the impact parameter may artificiality be increased by creating orbit pulsations near the scraper. The orbit pulsation amplitude value is defined like

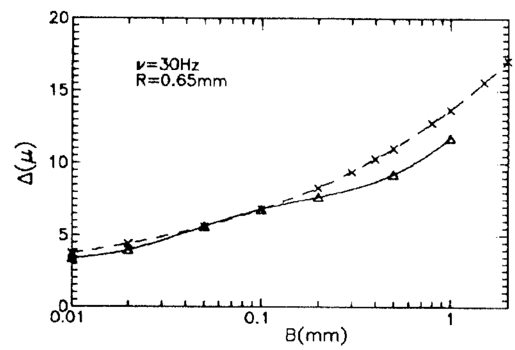

Figure 7: Dependence of the average impact parameter from the amplitude of orbit pulsations.

$B = \eta \times \Delta p/p$ and period is equal to period of synchrotron oscillations. Period of synchrotron oscillations T, half size of the beam near the scraper 3σ and average impact parameter of the particles with Δ_0 and maximum moment Δ_{max} are presented in table 1. That is the value of the impact parameter of the particles at the scraper has increased in several times.

Table 1

Parameters of the beam and impact parameter:

	3σ mm	V_0 mm/turn	T turn	B μm	Δ_0 μm	Δ_{max} μm
UNK1	10.0	4×10^{-5}	1000	3.0	2.5	33.
UNK2	4.0	4×10^{-6}	1000	1.5	0.4	7.6

Creation of dispersion in place scraper system installed serves as for scraping the particles, which escape from accelerating regime, as for increasing impact parameter of the particles at the scraper. This is particularly important if we use scraper system without scattering target.

When we change velocity of guiding beam by special way, as shown on fig.5 by dashed line, the value of the impact parameter will be close to single step of orbit. Step size is defined by thermal limitation of the scraper. For UNK that value equals several hundreds μm. Correspond increasing of the impact parameter may be used for beam extraction with the help of banding crystals and for decreasing radiation and thermal heating of his edge.

With using of scattering target the value of the impact parameter may significantly increase, but part of the particles go out from the target and may fall on the equipment. Computer simulations show that in case of using the W target we have $\Delta \sim 10mm$. When slanting scraper will be used for UNK the impact parameter will be increased in order.

4 REFERENCES

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